Microalgae as a Platform for CO_2 Capture and Utilization

Dr. Alvin B. Culaba, PhD
University Fellow and
Professor of Mechanical Engineering
De La Salle University

Academician
The National Academy of Science and Technology

Career Milestones

BSME Graduate
ME License

1984 (21 years old)

University of the Philippines

1986

1987 PNOC

Asian Institute of Technology
(French Government Scholar)

1989

1990 De La Salle University

1992 University of Portsmouth, UK
(World Bank-DOST Scholar)

Tokyo Institute of Technology
(JSPS Exchange Scientist)

1996 Earned Ph.D. in Mechanical Engineering; ME Chair at DLSU

1997 University of Sussex, UK
Harvard University Science & Technology International Affairs
Consultant to the PHINMA Group of Companies

Consultant to 150 companies in the Philippines 2001

DOST Outstanding Science Administrator Award
CHED Oustanding HEI Research Award
Metrobank Outstanding Teacher Award
NAST Dioscoro L. Umali Medal

President, Philippine-American Academy of Science & Engineering

Academician, National Academy of Science and Technology
Philippine Energy Adviser
Who's Who in Philippine Engineering

2008

2009 Florida State University, USA; began algae work

President, National Research
Council of the Philippines

2011 Executive Vice President of DLSU

NRCP Lifetime Achievement Award

Board Member
Phil Electricity Market Corporation

2016 Research productivity: h-index 16

Establishment of the Algae BioInnovation Global Hub

?? National Scientist

DE LA SALLE UNIVERSITY
RELIGIO MORES CULTURA
MANILA

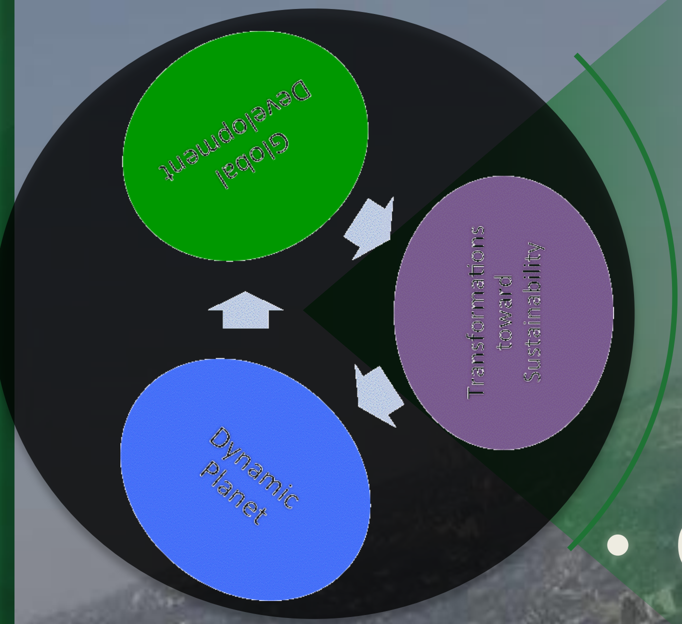
Major Energy Issues

Global Warming, Pollution, Energy Security

The Future of Humanity is at Risk

Source: Nobel Laureate Y.T. Lee at 81st Annual Meeting of the NRCP

Transformations towards Sustainability



decision making

- **Transformation process**

economy

mega-cities

development options

- **Innovation and ideas**

emerging technology

trade-offs

assessment of policies

- **Global and regional governance**

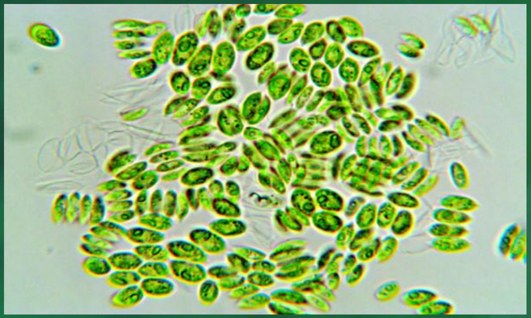
incentives

international law

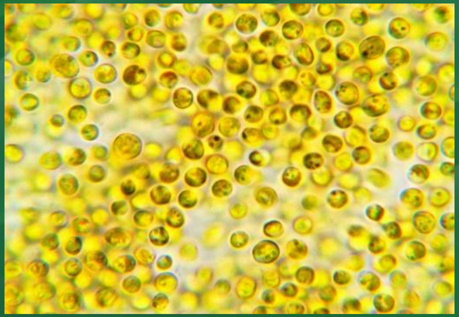
regional enforcement

Source: Nobel Laureate Y.T. Lee at 81st Annual Meeting of the NRCP

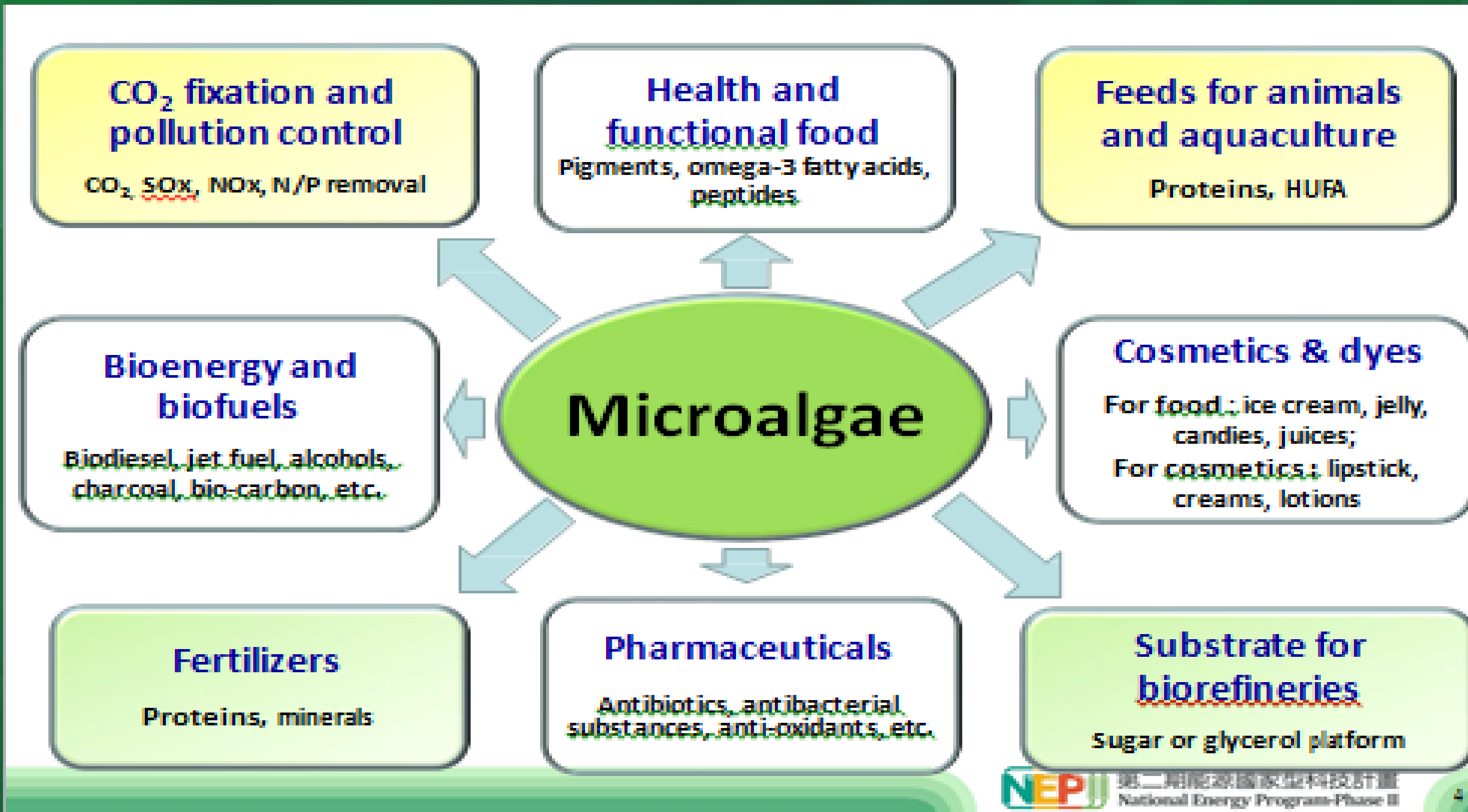
How can we capture and use the CO_2?

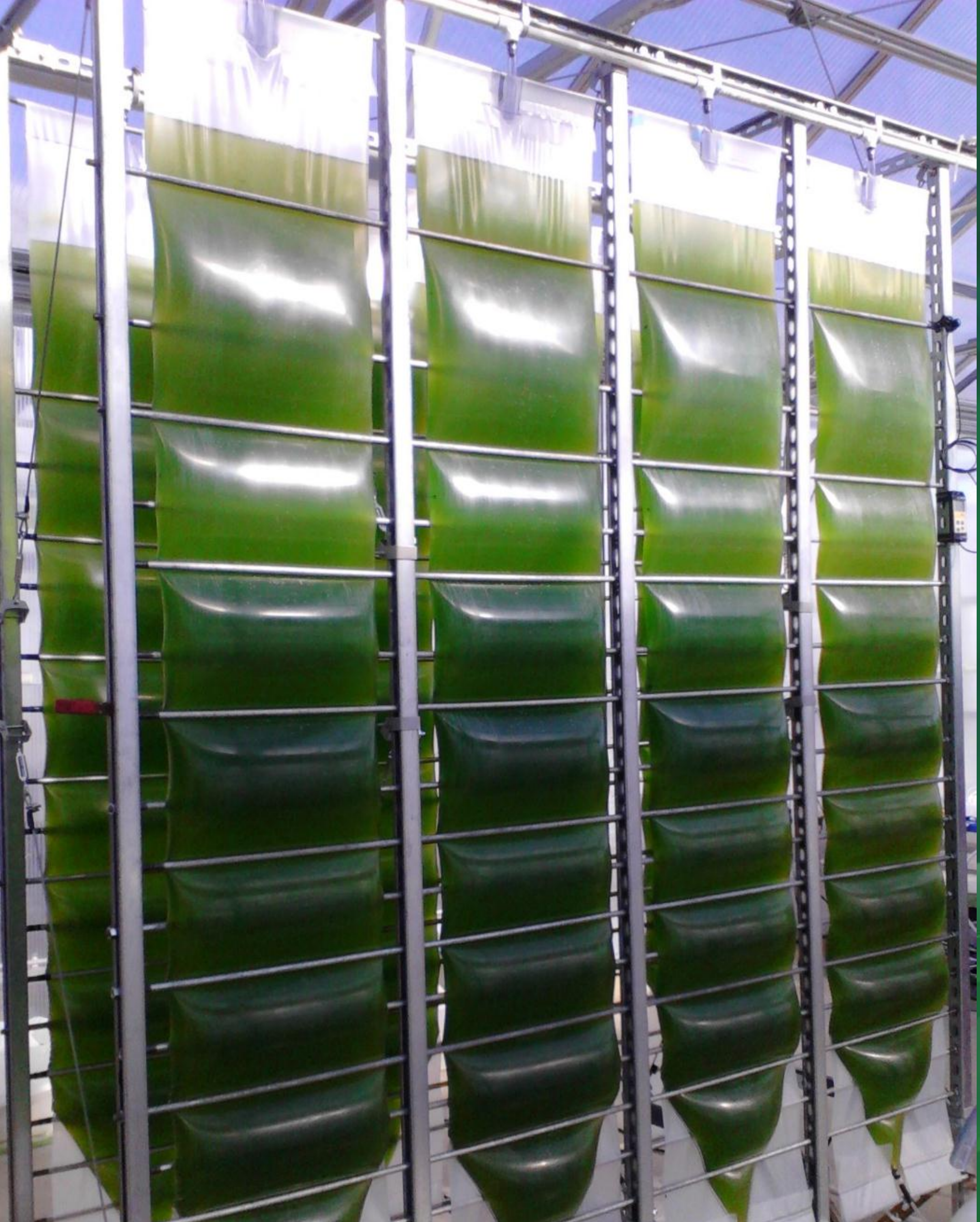


Use to grow ALGAE



Opportunities for Microalgae Use





Why Algae?

Omega 3 Oils Market Worth $4.3B by 2019

Astaxanthin Market Valued at over $1B by 2020

Global Bioproducts Market to Reach over $700B by 2018

Non-Energetics Bioproducts Market to Reach $236B by 2018

-- BCC Research

Adapted from the public lecture of Prof. Joel L. Cuello, PhD entitled *Building an Algae BioInnovation Global Hub* under the USAID STRIDE Innovation Series: Innovation Challenges in Growing the Algae Technology in the Philippines. DLSU-STC. January 2016

Why Microalgae?

Microalgae as Biomass Resource

- Exceptional growth characteristics
- Less nutrient input and land area requirement
- Minimum competition to productive land
- Wastewater treatment potential
- Carbon sequestration capability
- Size range: few to few hundred micrometers; length of 300-1,000 microns

Microalgae Biomass

Microalgae Biomass

- Biodiesel
  - Lipids / Oils
  - Fatty Acids
- Bioethanol
  - Sugar
  - Carbohydrates
- Animal / Aquaculture Feeds
  - Biomass Residues
  - Proteins / Pigments

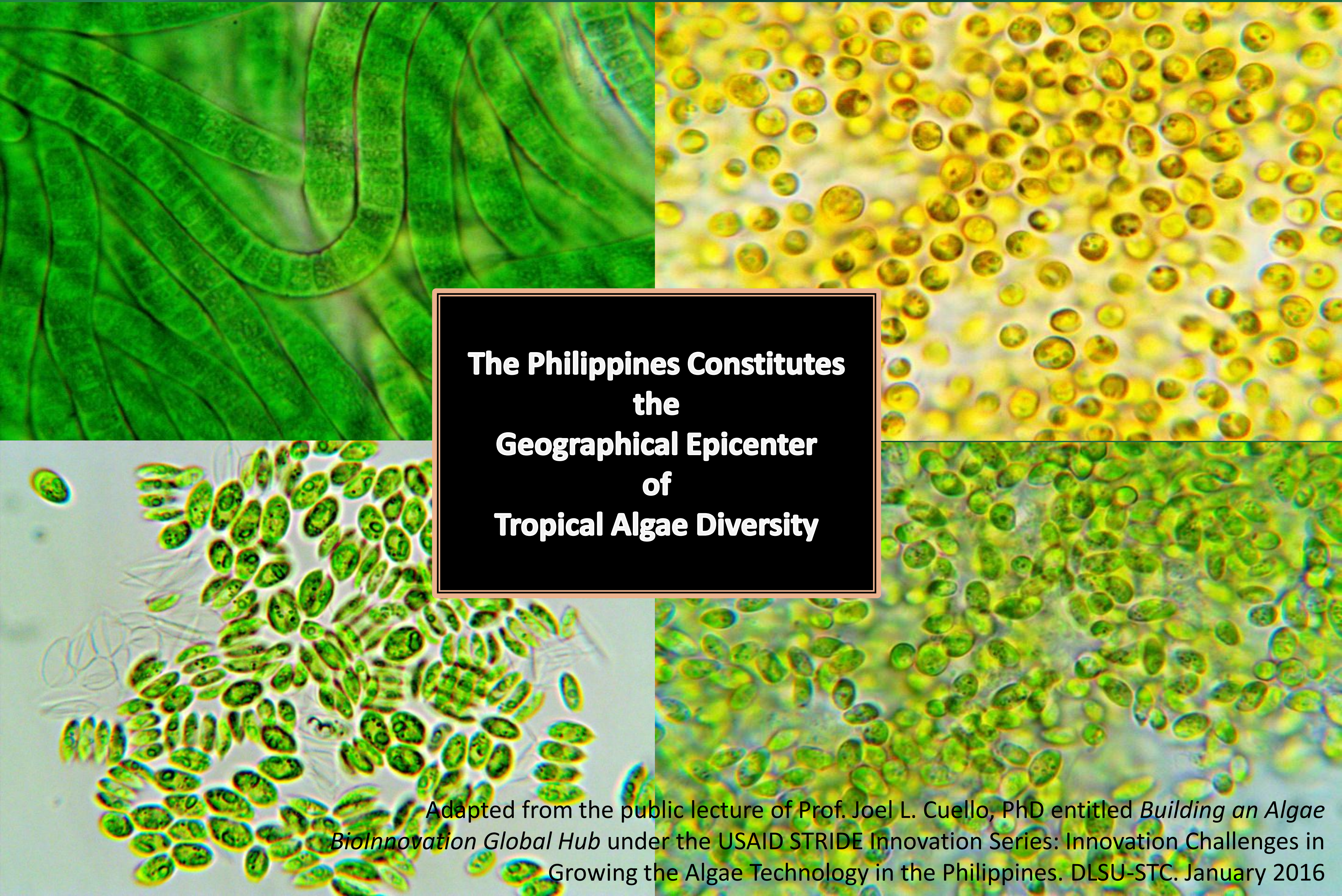
Gross Chemical Composition of Human Food Sources and Some Microalgae Strains

Commodity/ Microalgae Species	Protein	Carbohydrates	Lipids	Nucleic Acid
Baker's Yeast	39	38	1	-
Meat	43	1	34	-
Milk	26	38	28	-
Rice	8	77	2	-
Soybean	37	30	20	-
Scenedesmus obliquus	50-56	10-17	12-14	3-6
Scenedesmus quadricauda	47	-	1.9	-
Scenedesmus dimorphus	8-18	21-52	16-40	-
Chlamydomonas rheinhardii	48	17	21	-
Chlorella vulgaris	51-58	12-17	14-22	4-5
Chlorella pyrenoidosa	57	26	2	-
Spirogyra sp.	6-20	33-64	11-21	-
Dunaliella bioculata	49	4	8	-
Dunaliella salina	57	32	6	-
Euglena gracilis	39-61	14-18	14-20	-
Prymnesium parvum	28-45	25-33	22-38	1-2
Tetraselmis maculata	52	15	3	-
Porphyridium cruentum	28-39	40-57	9-14	-
Spirulina platensis	46-63	8-14	4-9	2-5
Spirulina maxima	60-71	13-16	6-7	3-4.5
Synechoccus sp.	63	15	11	-
Anabaena cylindrica	43-56	25-30	4-7	-

Based on a % Dry Matter Basis

Source: Becker (2008)

Prospects in the Philippines



The Philippines Constitutes the Geographical Epicenter of Tropical Algae Diversity

Adapted from the public lecture of Prof. Joel L. Cuello, PhD entitled *Building an Algae BioInnovation Global Hub* under the USAID STRIDE Innovation Series: Innovation Challenges in Growing the Algae Technology in the Philippines. DLSU-STC. January 2016

Common Microalgae Strains

Chlorella sp.

Scenedesmus sp.

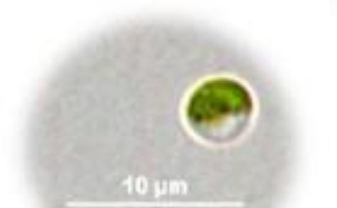
Scenedesmus sp

Nannochloropsis sp.

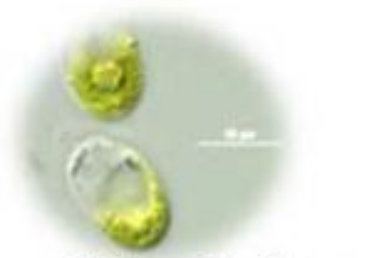
Golenkinia sp.

Auxenochlorella sp.

Micractinium sp.



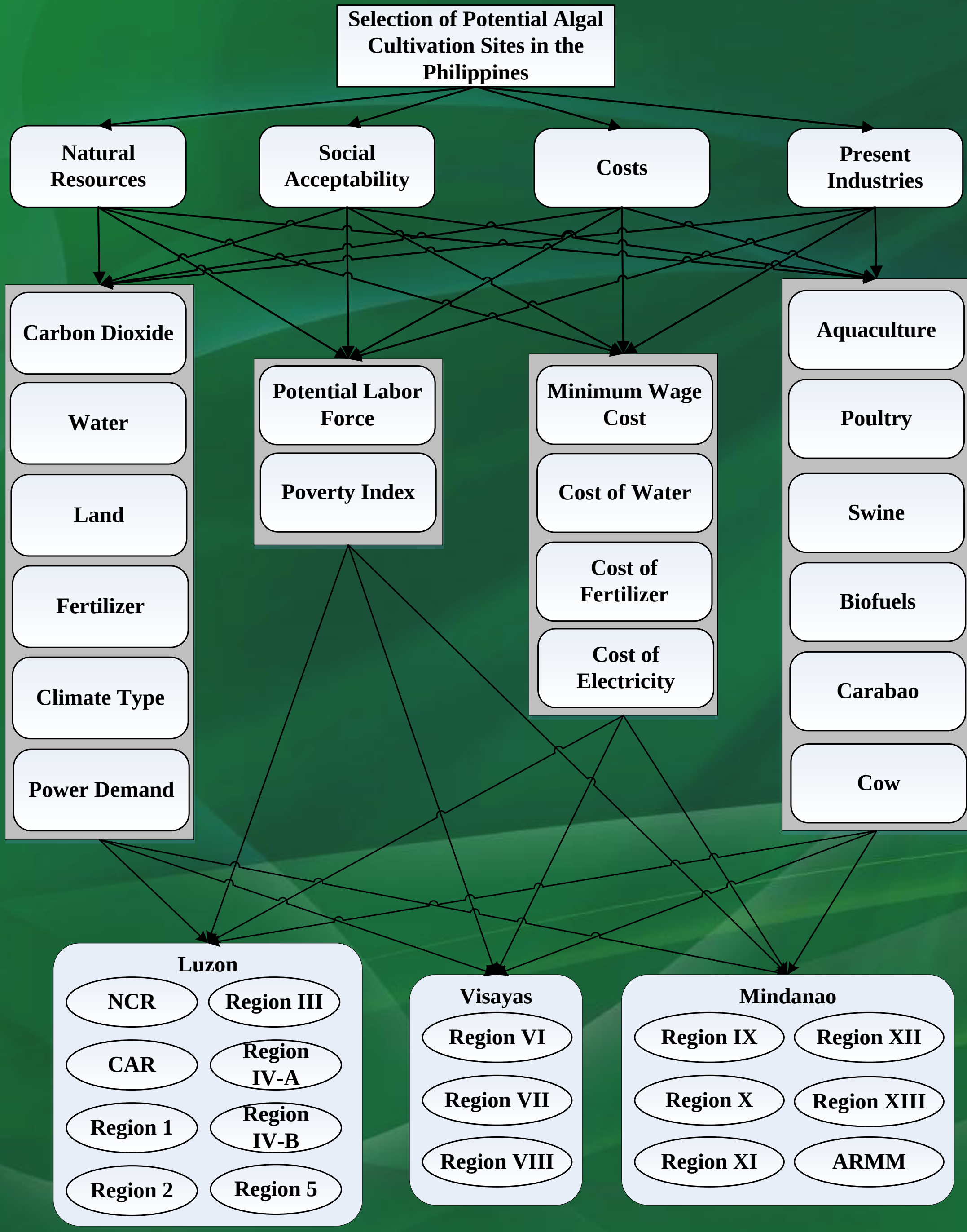
Picochlorum sp.



Tetraselmis sp.

Ankistrodesmus sp.

Actinastrum sp.



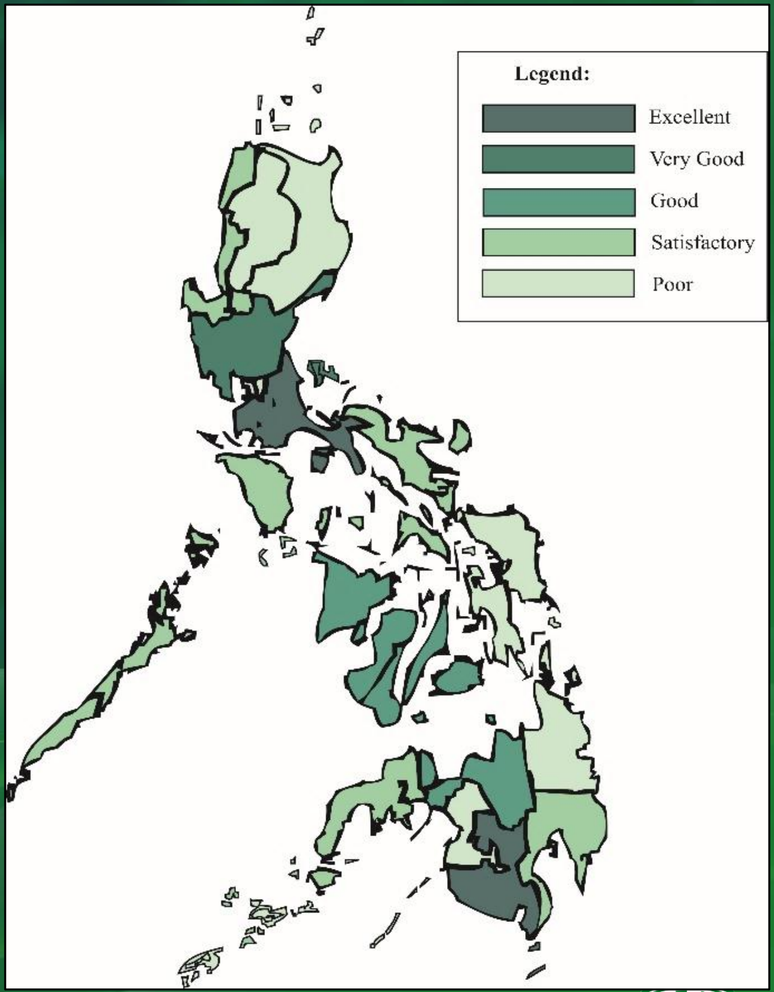
Deployment of a Microalgae Industry in the Philippines

Multi-Criteria Decision Analysis model in the evaluation of the most suitable cultivation sites in the Philippines

Ubando et al, 2015

Deployment of a Microalgae Industry in the Philippines

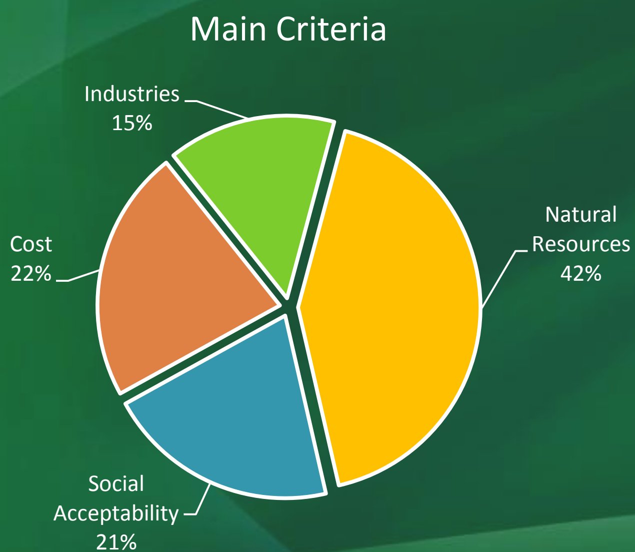
Ranking	Region	Weight, %
1	Region IV-A	11.47
2	Region III	9.22
3	Region X	8.73
4	Region VI	8.09
5	Region XII	6.39
6	Region VII	6.30
7	Region I	6.14
8	Region XI	6.04
9	Region IV-B	5.58
10	Region IX	5.37
11	Region V	5.31
12	Region II	5.17
13	ARMM	4.70
14	Region VIII	4.64
15	CAR	3.49
16	Region XIII	3.36

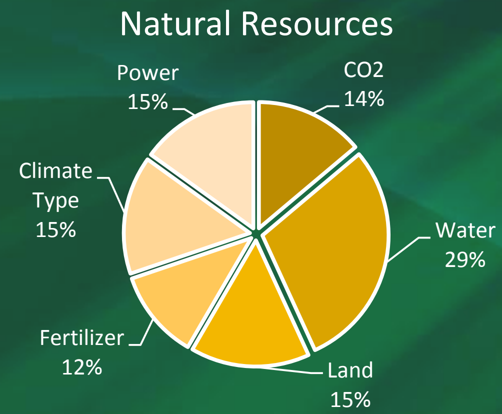


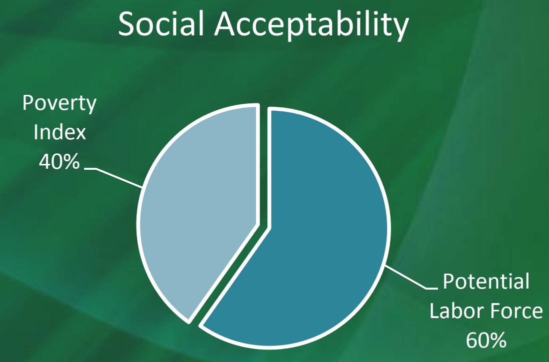
Deployment of a Microalgae Industry in the Philippines

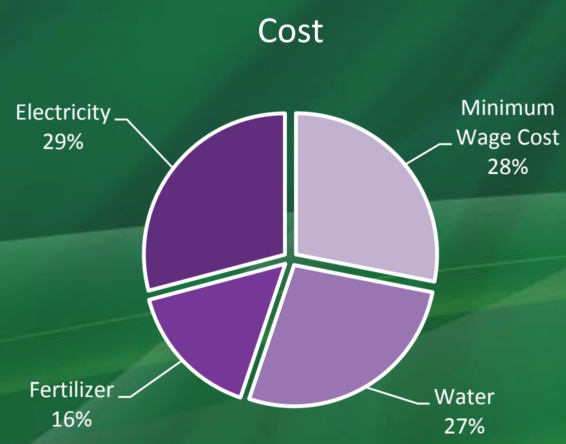
Main Criteria	Sub-criteria	Regional Data type	Units
Natural Resources	**Carbon Dioxide**	**CO2 source**	**Kg**
	Water	Water resources potential	MCM
	Land	Idle land capacity	Sq Km
	Fertilizer	Fertilizer use per region	50kg bags
	Climate Type	Climate projections	Normalized
	Power Demand	Fuel demand per region (mboe)	Million Barrels
Social Acceptability	Potential labor force	Labor force capacity per region	In Thousands
	Poverty index	Poverty incidence among families	%
	Minimum Wage	Cost per day per region	Php per day
Costs	Cost of Water	Cost of water per region per day	Php per cu m
	Cost of Fertilizer	Cost of inorganic fertilizer per 50 kg	Php per 50kg
	Cost of Electricity	Cost of electricity per kWh per region	Php per kWh
Present Industries	Aquaculture	Mt of aquaculture production per region	mtons
	Poultry, Swine, Carabao and Cow	Animal production	heads
	Biofuels	Capacities of existing biodiesel plants	Mli

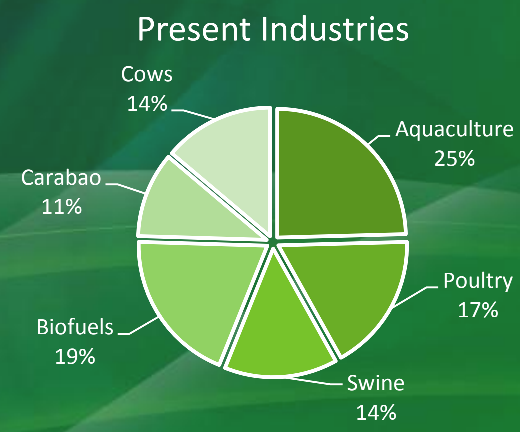
Deployment of a Microalgae Industry in the Philippines











Comparison of Biofuel Feedstock Sources

Crop or Plant Source	Oil Yield (L/ha year)	Land Use (m^2 year/kg biodiesel)	Biodiesel Productivity (kg biodiesel/ha year)
Corn	172	66	152
Hemp	363	31	321
Soybean	636	18	562
Jatropa	741	15	656
Camelina	915	12	809
Canola/Rapeseed	974	12	862
Sunflower	1070	11	946
Castor	1307	9	1156
Palm Oil	5366	2	4747
Microalgae (low oil)	58,700	0.2	51,927
Microalgae (med oil)	97,800	0.1	86,515
Microalgae (high oil)	136, 900	0.1	121,104

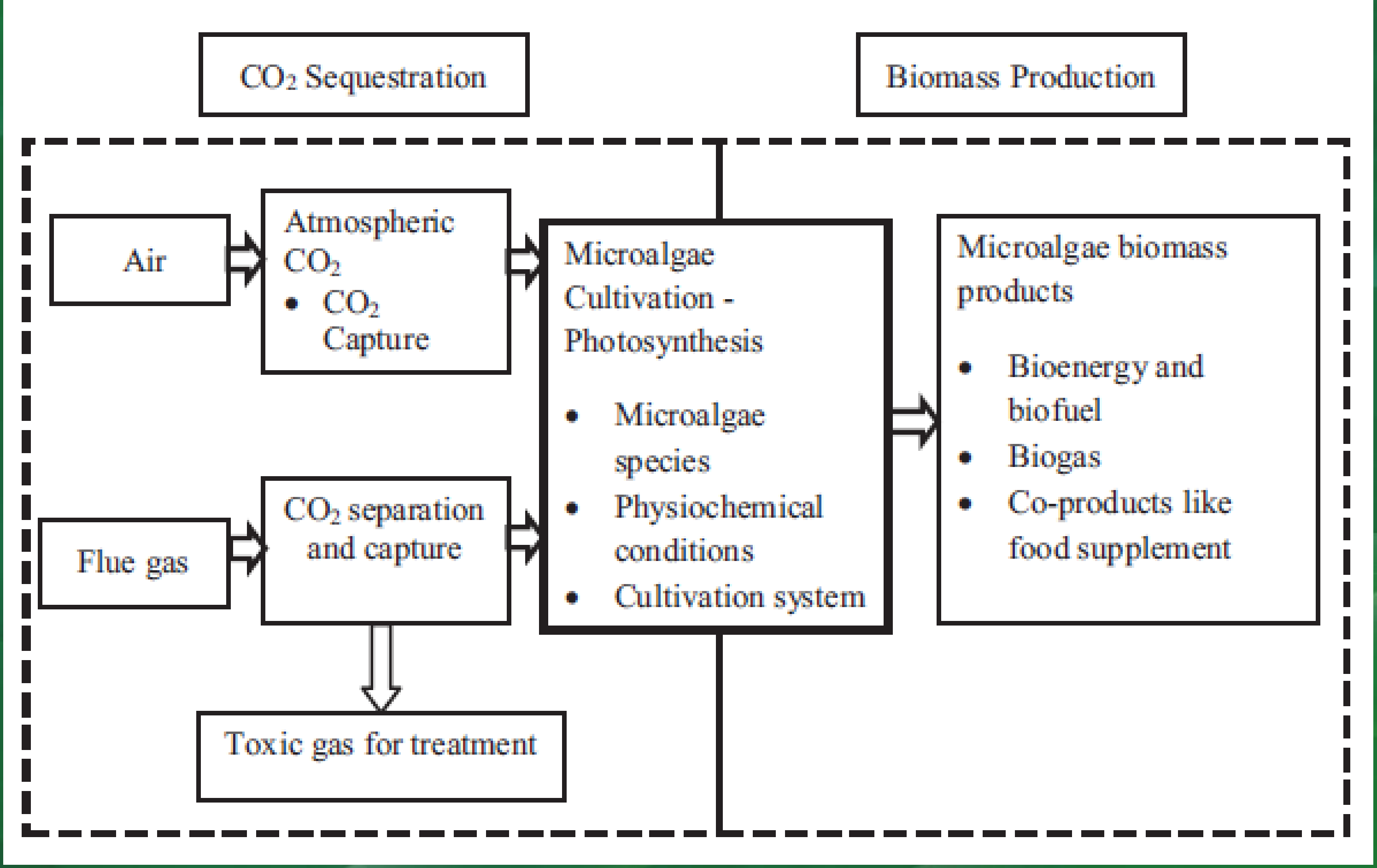
Source: Chisti, 2007; Mata et al., 2010

Lipid Content and Productivities of Different Microalgae Species

Marine and freshwater microalgae species	Lipid content (% dry weight biomass)	Lipid productivity (mg/L/day)	Volumetric productivity of biomass (g/L/day)
Botryococcusbraunii	25.0-75.0	-	0.02
Chaetocerosmuelleri	33.6	21.8	0.07
Chaetoceroscalcitrans	14.6-16.4	17.6	0.04
Chlorella vulgaris	5.0-58.0	11.2-40.0	0.02-0.20
Chlorella sp.	10.0-48.0	42.1	0.02-2.5
Chlorella	18.0-57.0	18.7	-
Dunaliellasalina	6.0-25.0	116.0	0.22-0.34
Dunaliellaprimolecta	23.1	-	0.09
Dunaliella sp.	17.5-67.0	33.5	-
Haematococcuspluvialis	25.0	-	0.05-0.06
Nannochloris sp.	20.0-56.0	60.9-76.5	0.17-0.51
Nannochloropsisoculata	22.7-29.7	84.0-142.0	0.37-0.48
Nannochloropsis sp.	12.0-53.0	37.6-90.0	0.17-1.43
Scenedesmus obliquus	11.0-55.0	-	0.004-0.74
Scenedesmusquadricauda	1.9-18.4	35.1	0.19
Scenedesmus sp.	19.6-21.1	40.8-53.9	0.03-0.26
Spirulina platensis	4.0-16.6	-	0.06-4.3
Spirulina maxima	4.0-9.0	-	0.21-0.25
Tetraselmissuecica	8.5-23.0	27.0-36.4	0.12-0.32
Tetraselmis sp.	12.6-14.7	43.4	0.30

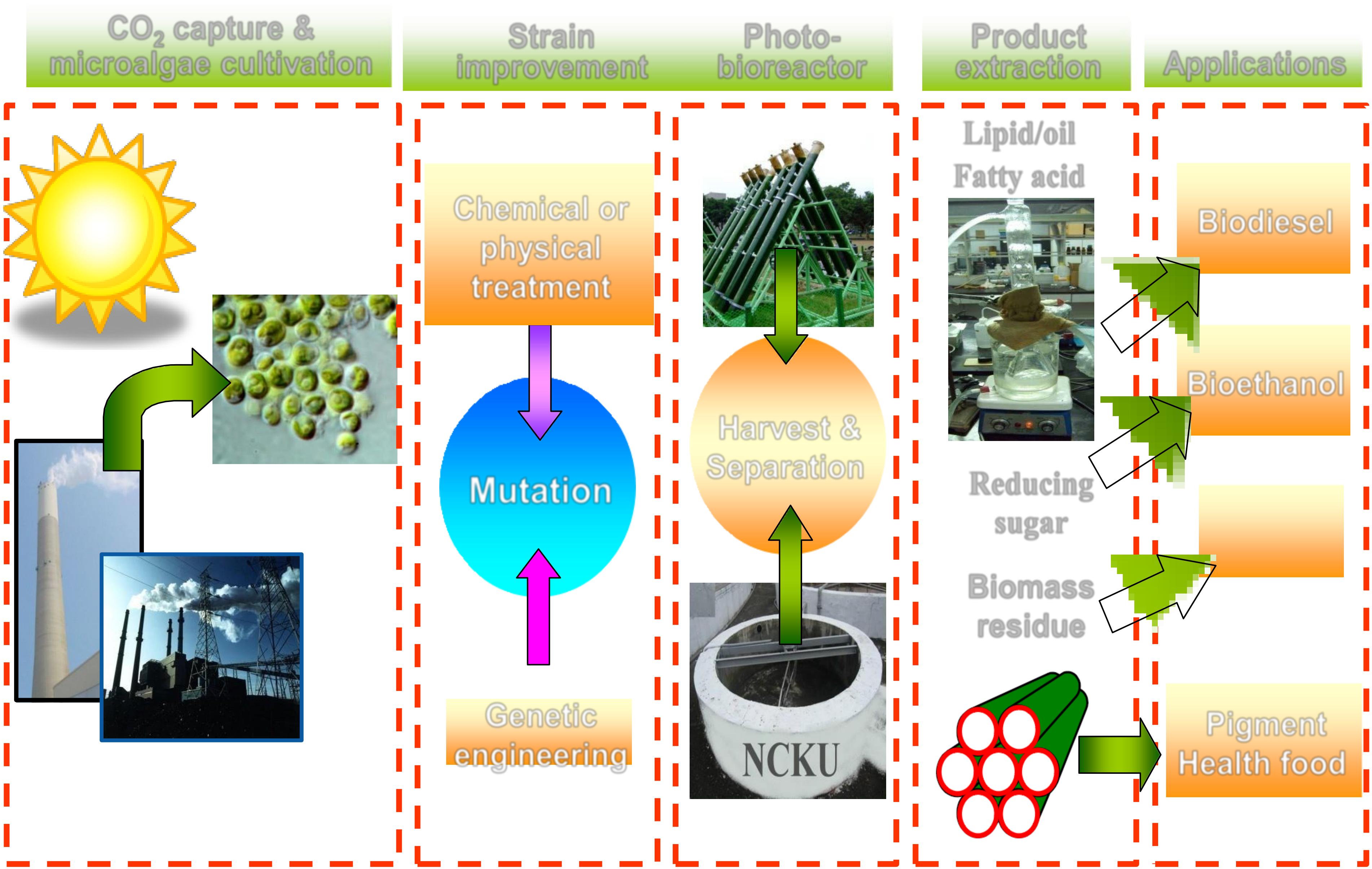
Source: Mata et al., 2010

Microalgal-CO2 Sequestration and Biomass Production



Source: Cheah et al, 2015

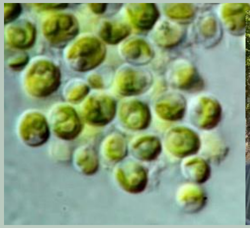
An Integrated Microalgae Technology for CO2 capture / Utilization



Microalgae for CO_2 Capture/Utilization

Cultivation

- Nutrient medium
- Sunlight or other light source
- CO_2 from flue gases and power plants
- Photobioreactor or Open Ponds



Strain Improvement

- Chemical or Physical treatment
- Genetic Engineering

Harvest and Separation

- Centrifugation
- Oil Extraction


Carbon from Flue Gases

Fossil Fuel Power Stations

Cement Processing

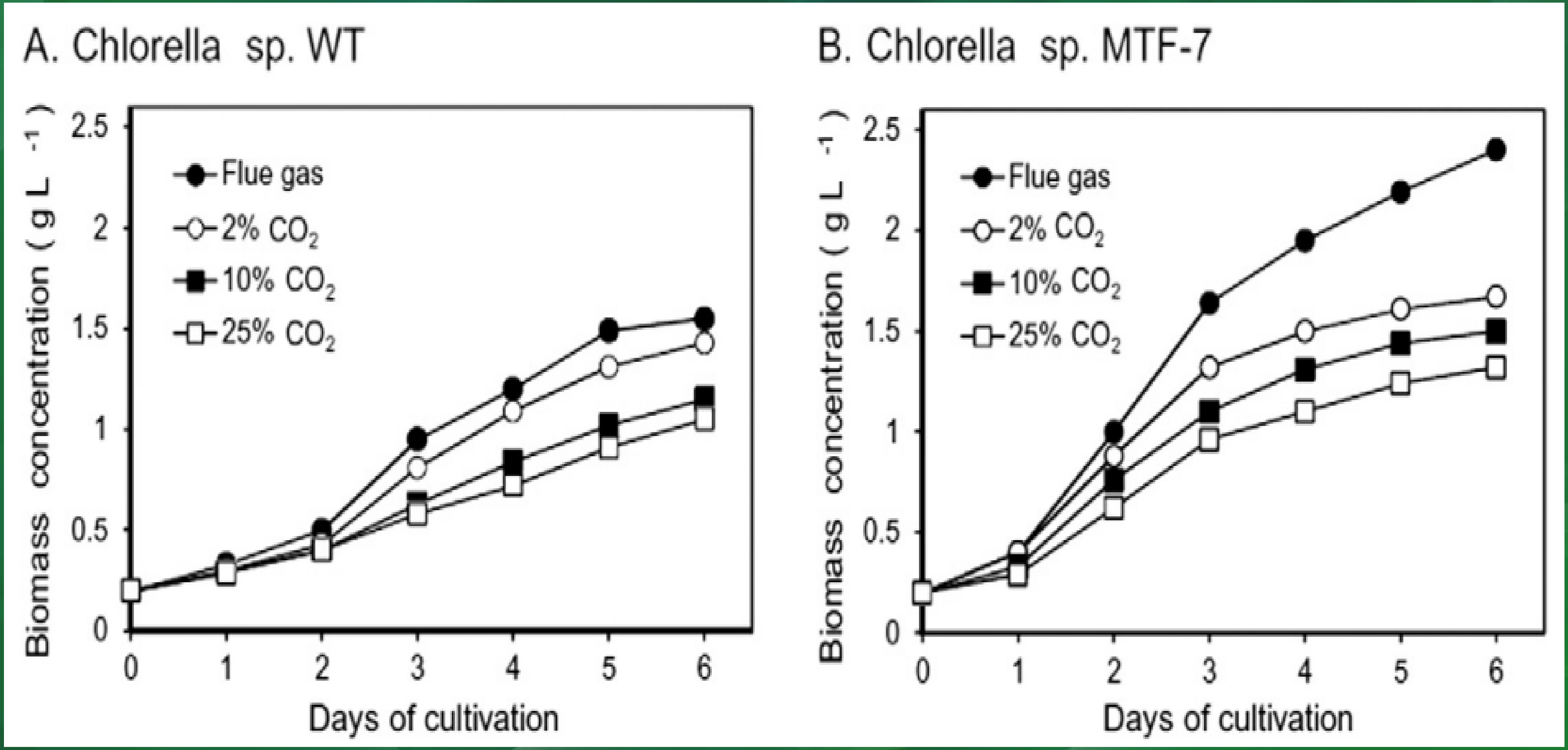
Automotive Industry

- Microalgae can grow on varieties of flue gas types.
- CO_2 reduction capacity is **300-500 ton CO_2/ha/yr** with a removal efficiency of **60-70%** (Taiwan NEP – II)
- Flue gas impurities such as NO_X and SO_X can be simultaneously removed as well

Carbon Sequestration: How it works

Source: http://reveal.uky.edu/algae_part1_howitworks

Microalgae Growth using Different Flue Gases



Source: Raeesossadati et al, 2014

Performance of Microalgae-based CO2 Fixation

- CO_2 reducton capacity is ca. **300-500 ton CO_2/ha/year**
- CO_2 removal percentage = f (flow rate, CO_2 concentration, photobioreactor type), can get up to 60-70% removal efficiency
- Microalgae can grow on varieties of flue gas types
- **Flue gas impurities (NO_x and SO_x)** can be simultaneously removed (up to 70-90%)
- The obtained microalgal biomass (150-250 ton biomass/ha/year) has been utilized to produce biofuels (biodiesel, bioalchols, charcoal, etc.) and also other value-added products

Research@DLSU: Life Cycle-based Multifunctional Bioenergy System Research

Optimization
(TA&MU, UNM, DLSU)
Dr. Tan /Dr. Foo/ Dr. Ng/ Dr. El-Halwagi / Dr. Aviso/ Dr. Promentilla

Process Systems Engineering, Pinch Analysis, Biorefinery, Analytical Hierarchy Process

Cultivation
(UPV, UPLB)
Prof. Toledo / Dr.

Tetraselmis Sp., Nannochloropsis, Chlorela vulgaris

Cultivate other strains

Biofuels

Products

BIO-ENERGY

Algae

Microalgae

Drying Technologies
(DLSU, UA, UPD)
Dr. Culaba/ Engr. Ubando /Dr. Cuello / Dr. Biona

Convective Heat, IR, RF

Other Drying Tech: Freeze; Microwave; Combined

Chemical Process
(UPD)
Dr. de Leon

Molecular
(OU, DLSU, PhERNeT)
Dr. Kasai/ Dr. Arboleda/ Dr. David/ Dr. Villagracia

Characterization *Chlorella vulgaris*

Characterization of other strains

Bio-energy
Dr. Razon

- Various strain for NH_3 and biofuels
- Microalgae for water treatment

Socio-Economic
Prof. Tanchuco

Economic Analysis

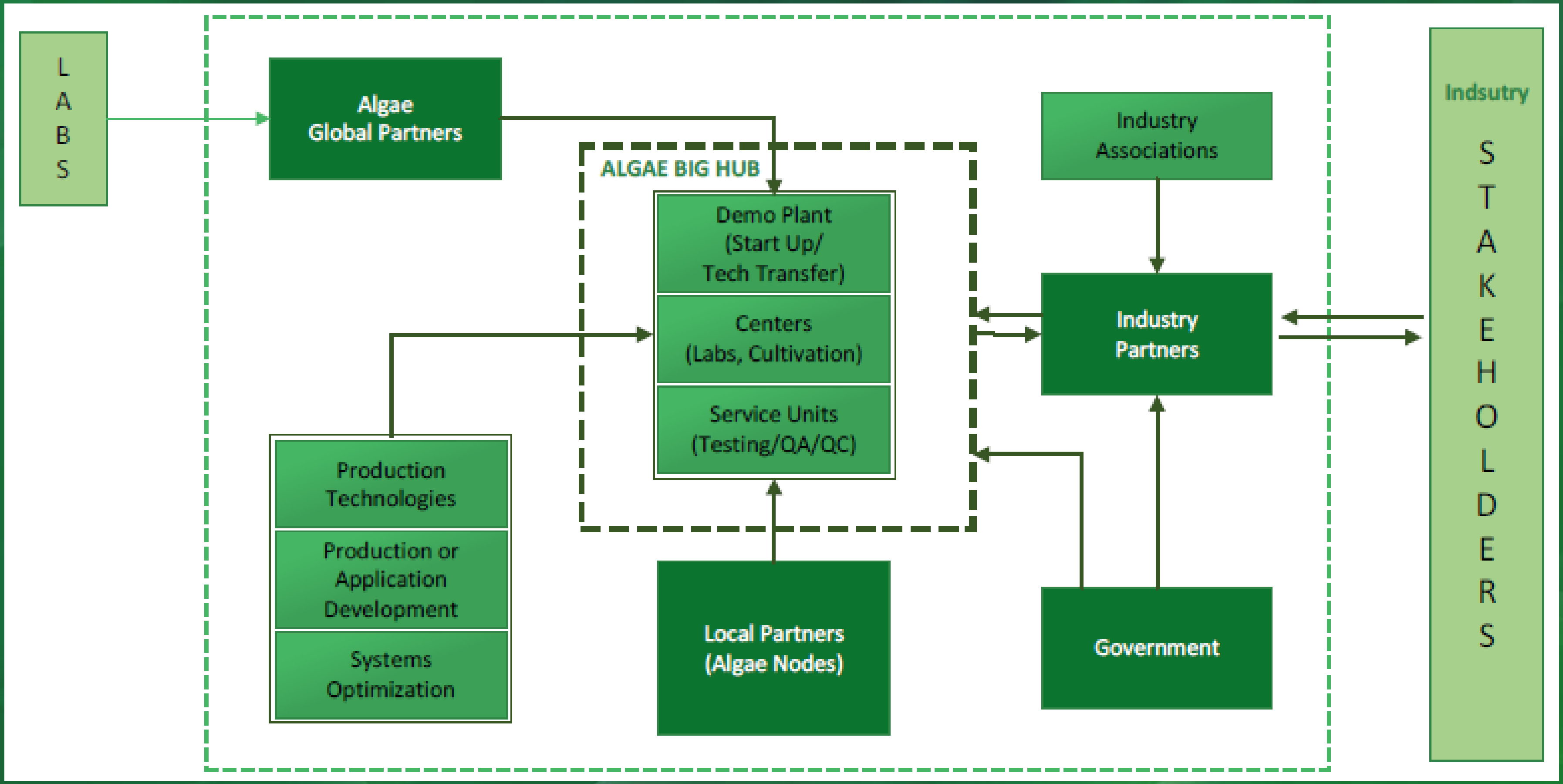
Legend
Process

Members

On-going Research

Possible Research Topics

Algae S&T Innovation Ecosystem



Establishment of the Algae BIG Hub

Name

- **Algae BioInnovation Global Hub Philippines** (A BIG Hub – PH)

Headquarters

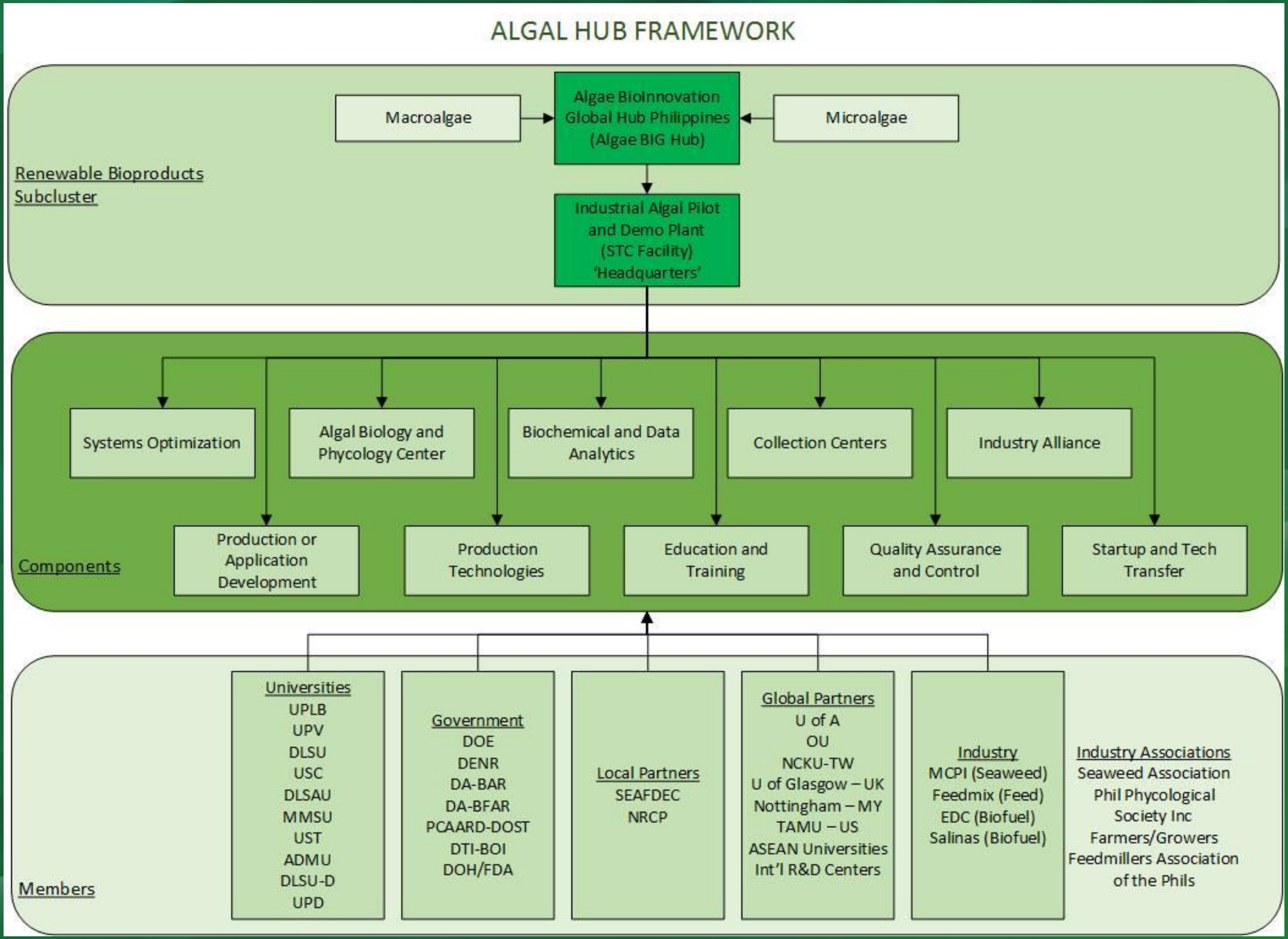
- De La Salle University Science and Technology Complex (DLSU-STC), Biñan Laguna

Mission-Vision

- To serve as the regional hub for algae-based resources, knowledge, technologies and multidisciplinary expertise for the purpose of creating and designing algae-based innovations for food, feed, nutraceuticals, biofuels and all types of products for translation into the marketplace

Function of the Hub

- To provide scientific knowledge to anyone who are interested in algae research & development



Open Pond / Closed Photobioreactor

Open Pond Cultivation System
at UP Visayas

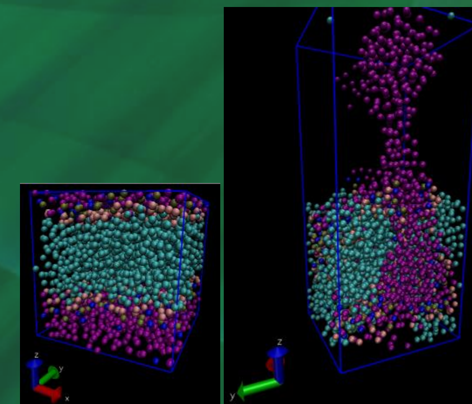
Open Pond Cultivation System
of AZtec Spirulina in Cainta

Closed PBR system at DLSU Manila

Microalgae Dewatering (for Biofuels Production)

Drying

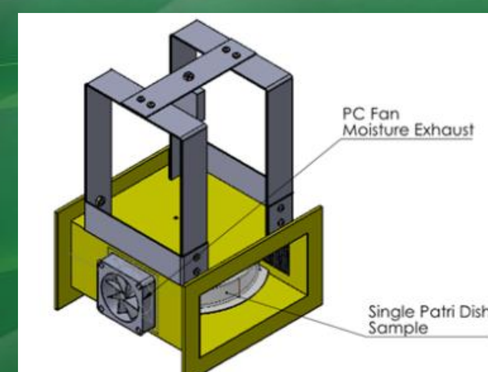
Solar
(Ubando, 2012)



Molecular Dynamics
(Manrique, 2013)

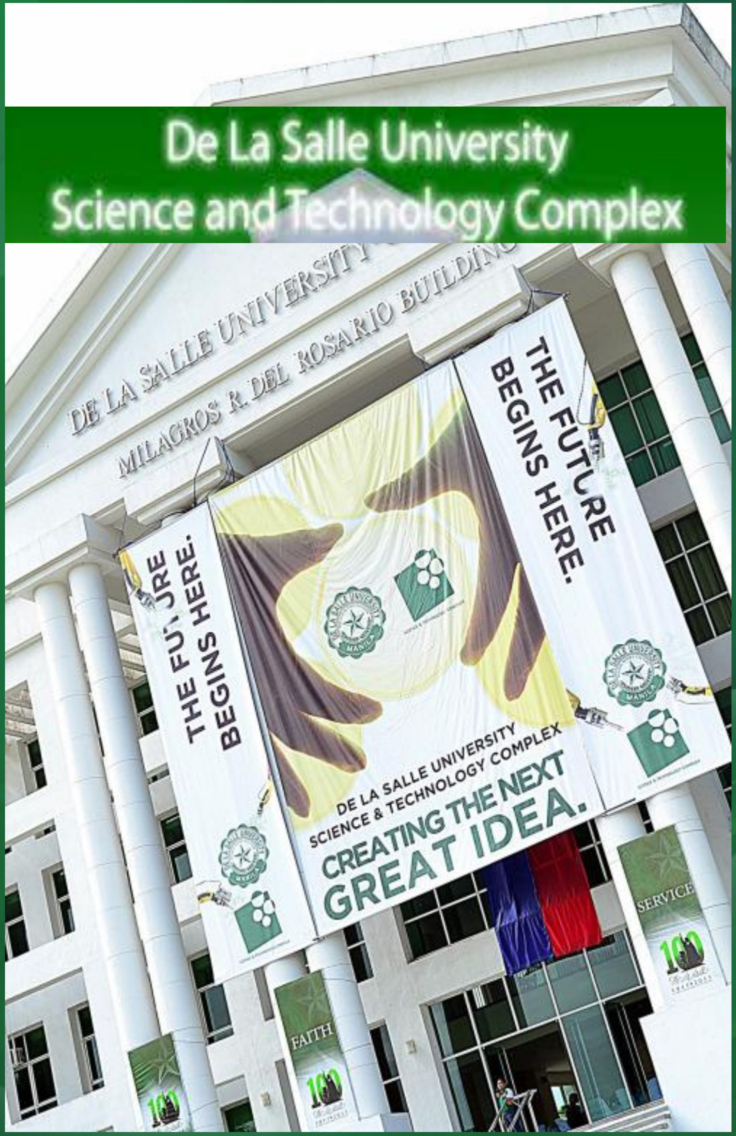
Convective
(Doblada, 2014)

Infrared
(Tono et al., 2013)



Microwave
(Mayol et al, 2014)

The Algae BIG Hub@DLSUSTC



Conclusions

- Microalgae can be used to capture CO_2 for greenhouse gas mitigation.
- Incorporating flue gases and wastewaters for microalgal cultivation makes production more environmentally sustainable.
- Microalgae biomass contain numerous functional chemical components which can be processed into high-value products.
- There is a high potential in investing on microalgal biorefineries in the Philippines.

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Acknowledgements

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  - Professor of Chemical Engineering
  - National Cheng Kung University, Taiwan
- Dr. Joel Cuello
  - Professor of Bioenergy Systems
  - Collaborator, University of Arizona, USA

THANK YOU.